Bridging the gaps between ecological principles and actions for designing biodiversity-based agriculture

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1 Introduction

In developed countries, a production-oriented agriculture was intensively promoted after World War II. It is based on the use of "off-the-shelf" technologies (synthetic inputs, fossil energy, genetics…) that limit, as much as possible, the effect of reducing production factors and level the heterogeneity of the environment. This model led to a standardisation of production methods and to a specialisation of territories according to their suitability for specific land uses. In the 1980s, the negative effects of this production system on biodiversity, ecosystems, global changes, and human health started to emerge. Moreover the increasing scarcity of fossil resources, healthy soils and water started to be a society concern. Objectification of the negative impacts of agriculture and redefinition of the objectives of agriculture in agricultural policies have led to two forms of ecological modernisation of agriculture (Horlings and Marsden, 2011). One, in continuity with the production-oriented agriculture aims at increasing the resource-use efficiency. It does not fundamentally renew the features of scientific knowledge production mode. The second, departing from the production-oriented model, aims at developing biodiversity to produce ecosystem services (ES) that support production and regulate flows. Provision of these ES requires managing biodiversity at field, farm and landscape levels (Kremen *et al.*, 2012). We focus on issues related to the implementation of biologically diversified farming systems and landscapes.

2 Foundations and issues of a biodiversity-based agriculture

Increasing biodiversity in space and time is expected to provide ES to agriculture (eg. soil fertility conservation, biological control of pests) and to society at local (eg. water regulation) or global scales (eg. climate regulation). ES to agriculture are of particular importance because they offer opportunities to farmers to strongly reduce use of synthetic inputs. Several authors (e.g. Altieri, 1999) agree about three prime-order agroecological principles for designing agricultural practices that favor these ES: (i) increasing plant diversity and soil cover through adapted crop sequences (cover-crops, varieties or species mixtures)to decrease nutrient and radiation losses and increasing above and underground biomass production and rhizosphere deposition to, in turn, increase biological, physical and chemical soil fertility, and biological regulations; (ii) minimizing mechanical and chemical disturbances of soil functioning and, whenever possible, seeding or planting directly into untilled soil to increase soil organic matter to support development of soil micro-, meso- and macrofauna for promoting soil fertility, biological regulation, and hence improve soil structure; (iii) organizing the landscape matrix (spatial crop distribution, grass trip, hedgerow, other semi-natural habitats…) to increase biological regulations favoring natural pest control and pollination.
However, implementing agricultural systems based on these principles remains difficult because locally-relevant knowledge on relationships between management practice, biodiversity, and ES is still incomplete, especially when ES depend on associated biodiversity (eg. micro-, meso- and macro fauna: Bommarco *et al.*, 2013). Therefore, promoting biodiversified farming systems and landscapes requires site-specific transformational changes. Management practices for enhancing ES need to be adaptive and flexible. Farmers practicing biodiversified agriculture usually proceed by trial-and-error process, sharing their experience with their peers to facilitate and accelerate learning and in turn limit risk. This is akin to what is called "adaptive management" in science, *i.e.* iteration of design and implementation of actions, monitoring of their effects, learning about agroecosystem functioning (William 2011). This leads researchers to produce methods and tools that are: (i) flexible enough to take local specificities into account and to integrate both emergent scientific and local knowledge, (ii) integrative, to reproduce with adequate accuracy the emerging properties of complex assemblages of species and practices, (iii) learning-oriented to promote the development of local knowledge, and (iv)a means to cope with uncertainty within an adaptive management scheme.

3 Building learning-oriented support tools to link principles and actions

To reach these above objectives, and from our diverse experiences, we argue that the development of learning-oriented tools should be collegiate (*i.e.* involving scientists, extensionists, farmers and other stakeholders), to stimulate knowledge exchanges. Because the main objective is to design a consistent foundation of the complex agroecosystem to implement and manage, user-friendliness and accuracy of predicted effects of management practices are also important characteristics. To support the key steps of the adaptive management they have to be useful both to design farming systems and to assess the ecosystem benefits that they bring.
Researchers, farmers and agricultural advisors are not well-equipped to deal with design of complex adaptive systems and assessment of their dynamics. Few mechanistic models dealing with agroecosystems address relations between management, biodiversity and ES. Most existing models focus on representations of the plant-soil-atmosphere system with mechanistic modeling of abiotic resources interactions and effects on plant production (energy, water, N, C). Given the expected features of learning tools, we identify three main types of emergent support tools likely to be helpful to lead the transition toward biodiversity-based agriculture: (i) knowledge bases, (ii) model-based, (iii) farm-landscape indicators usable by farmers and allowing them to think about past effects and predicting effects of future actions:

i. Knowledge bases contain structured scientific facts and empirical information compiled from cumulative experiences that enable biodiversity management to be inferred in specific situations. They have been developed recently, for example, to help selecting cover-crop species by providing information about suitable production situations (main cropping system, climate, soil) and expected ecosystem services. Some are built from plant-trait-based functional profiles (Ozier-Lafontaine *et al.* 2011), while others rely on expert knowledge about plant features (e.g. Naudin *et al.* 2011). A challenge would be to allow consolidate these knowledge bases with practitioner's feedbacks.
ii. Model-based games allow designing potentially adapted farming systems and even landscape organizations through stimulation of knowledge exchange and learning about the effects of planned and associated biodiversity on ecosystem services. They can be used to perform iterative design and *ex-ante* assessment of spatiotemporal distributions of crops, livestock and semi-natural habitats potentially promoting input services. These participatory-design approaches are based on manipulating “boundary objects” such as board games, cards, geographic or cognitive maps and computer models to create a shared language among the actors involved (e.g. farmers, advisors, students, scientists, other stakeholders). Materials and computer items are used either simultaneously or successively to collectively design and assess alternative farming systems (Martin *et al.* 2011) or landscapes.
iii. Finally field-farm-landscape indicators are necessary to reveal aspects of agroecosystems that provide ecosystem services to be estimated. Such aspects first include the soil state, for which several indicators already exist and are used. However, indicators of the balance between noxious, beneficial and neutral soil organisms, hence of the real or potential natural pest control of soil, have to be made available, in a simplified form, to farmers. Surprisingly little is known about the status of farmland biodiversity and how it changes under different farming practices. A new toolbox, called the “BioBio indicator set” (Herzog et al 2013), has recently been developed for a variety of farm types and scales in Europe. It is the fruit of a close collaboration between scientists, environmentalists and farmers, which imparts saliency to the toolbox.

4 Prospects for a research agenda

The development of learning tools to support biodiversity-based agriculture is still in its infancy. To develop toolsin the line with an adaptive management frame, we propose to combine several scientific disciplines: (i) advances in ecological science for characterizing, first, planned and associated-biodiversity responses to locally controllable or exogenous drivers, and, second, effects of biodiversity on ecosystem services, (ii) advances in management and design sciences for designingmethods facilitatingthe collaboration betweenstakeholders involved in biodiversity-basedagriculture and farmers, and the evaluation of these collaborations, and (iii) agricultural and social sciences for building learning-support tools taking into account their use.

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